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PRIMARY BATTERY SESSION UTILIZATION OF THE MG/MNO2 DRY CELL SYS--ETC(U)
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Primary Battery Session

UTILIZATION OF THE Mg/MnO₂ DRY CELL SYSTEM

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Two methods for improving the performance characteristics of the magnesium dry cell have been explored. In the first approach, the improvement was obtained with a hybrid system consisting of the magnesium/manganese dioxide (Mg/MnO_2) dry battery and the nickel cadmium (Ni-Cd) rechargeable battery under intermittent discharge conditions. In the second approach the benefit in performance was achieved by insulating the Mg/MnO_2 battery against heat losses. The combined influence of both approaches lead to very substantial improvements in low temperature, high current discharge performance.

The Hybrid of Battery BA-4386/PRC-25 and a Ni-Cd Battery

Experiments using Magnesium Battery BA-4386/PRC-25 in a hybrid configuration with an assembly of sealed Ni-Cd cells were presented at the 25th Power Sources Symposium.[1] Under this program experimentation was continued on 1 min/9 min and 1 min/4 min duty cycles under a variety of load conditions. These represented different applications, each of which require a battery power source that does not exhibit the delay characteristic associated with the magnesium dry battery. Different capacity Ni-Cd batteries were used to determine which particular capacity would be best suited for the duty cycles and loads used. In a second series of experiments using the BA-4386/PRC-25, a coulometer was used as a charge control device for the Ni-Cd battery.

A summary of the data obtained at 70°F in the first series of experiments is presented in Figure 1. The improvements resulting from the hybrid design are evident. On the 1 min/9 min duty cycle, the improvement in service increases from 33% for the 7.0 ohm/50.0 ohm loads to 100% on the 4.0 ohm/83.3 ohm loads. The benefit obtained from the hybridization becomes less significant on the 1 min/4 min duty cycle, particularly under the 14.2 ohm/100 ohm condition. As shown in Figure 1, on the 1 min/9 min duty cycle, near maximum capacity of the hybrid system can be obtained with the 250 mAh Ni-Cd battery with no advantage being gained by using a larger capacity Ni-Cd battery.

With a hybrid design using a 250 mAh nickel cadmium battery and the primary battery weighing 2.5 pounds and measuring 65 cubic inches, the Ni-Cd battery adds only 15% to the weight and 11% to the volume.[2] Table I shows a comparison of energy density and capacity for the BA-4386/PRC-25 alone and the hybrid configuration for the indicated loads on a 1 minute/9 minute duty cycle.

Charge control was not employed in the foregoing experiments. However, it was anticipated that, as the operating temperature rose above 70°F, the voltage difference between the two battery types would become larger. This voltage condition causes wasteful overcharge that could damage the Ni-Cd battery as the temperature rises. To avoid the overcharge and the damage, a 1.0 Ah Cd-Cd coulometer with a by-pass diode in parallel with it were placed between the primary battery and the secondary battery as shown. When fully charged, the voltage of the coulometer rises until it is clamped by the by-pass diode. This increase in voltage limits the current flow from the primary battery to the Ni-Cd battery. A 250 mAh coulometer,

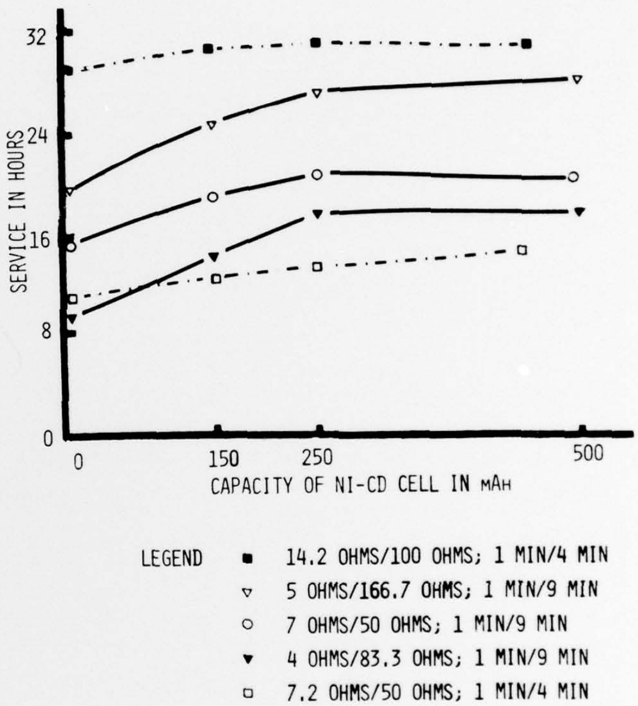

Figure 1. Hybrid System Service Versus Nickel-Cadmium. Cell Size on Indicated Duty Cycle.

TABLE I
COMPARISON OF ENERGY DENSITY AND CAPACITY

	BA-4386/PRC-25		BA-4386/PRC-25 With Ni-Cd Battery	
Loads In Ohms	Wh/Lb	Ah	Wh/Lb	Ah
7.0/50.0	31.6	6.0	37.2	9.1
5.0/166.7	25.7	5.6	31.5	8.1
4.0/83.3	17.3	3.7	29.2	7.5

matching the capacity of the Ni-Cd battery, was preferred but unavailable; however, it would have acted in about the same manner as the 1.0 Ah device.

The coulometer and the Ni-Cd battery were always fully charged at the start of an experiment. During the evaluations a particular coulometer and secondary battery remained together so that they would be fully charged at about the same time.

Presented in Table II is a comparison of hours and ampere-hours obtained with and without a coulometer charge current control circuit in an experiment with a 1 minute/9 minute duty cycle, a fixed load of 7.2 ohms for the 1 minute period, and various loads for the 9 minute period. The use of the charge control circuitry shows a significant advantage at 100°F where there is no 9 minute load to limit the charging current. Under the other test conditions, the influence is not as significant.

TABLE II
MEAN CAPACITY IN HOURS/AMP-HOURS TO 10.0 VOLTS END VOLTAGE

	9 Minute Load in Ohms	Test Temperature in °F 100	70	20
With Coulometer	Open Circuit	60.4/9.7	54.0/8.2	10.5/1.7
	166 2/3	39.5/8.9	34.9/8.9	7.0/1.5
	50	22.2/8.4	18.1/8.2	Erratic
Without Coulometer	Open Circuit	47.8/7.6	48.8/7.4	10.7/1.6
	166 2/3	- - -	31.9/7.0	6.3/1.4
	50	20.1/8.0	17.5/7.9	Erratic

Voltage delay did not occur with the hybrid configuration except at 20°F where it took two 1 minute discharges to reach minimum operating voltage, after which no delays were observed.

Battery Operating Temperature and its Effect on Performance

During discharge the Mg/MnO_2 battery generates heat, the amount being a function of the current drawn.[3] To establish the benefits to be derived by insulating a battery to retain this heat during discharge, evaluations were conducted. In addition, the effect of high operating temperatures on the Mg/MnO_2 cell was also studied, since an insulated battery could obtain a high operating temperature under certain use conditions.

The influence of high operating temperatures on battery capacity was determined by discharging individual "CD" size cells measuring 3.3" in height and 0.935" in diameter to a cutoff voltage of 1.25 volts under the load conditions and temperatures indicated in Table III.

Below 100°F, the capacity of the Mg/MnO_2 dry cell decreases as the temperature falls, exhibiting a sharper decline as the current drain is increased;[3] this is not the case above 100°F. As would be expected, an increase in ambient temperature results in a rise in operating voltage, but the increased voltage does not account entirely for the decrease in service observed. At 220°F, a lower ampere-hour capacity was obtained on each test when compared to the 130°F results; this behavior can be attributed to moisture loss.

TABLE III
CAPACITY FOR INDIVIDUAL "CD" SIZE CELLS

Loads in Ohms:	7.5*		30.0*		2.5/50**	
Discharge Temperature In °F	Hours	Amp-Hours	Hours	Amp-Hours	Hours	Amp-Hours
220	21.5	4.82	58.0	3.64	36.2	3.51
130	28.0	6.05	89.2	5.09	50.0	4.56
74	19.5	3.68	102	5.44	59.0	5.17

*Discharged continuously

**Discharged on a 2/18 minute duty cycle, repeated continuously

When designing a battery and battery compartment for operation where high battery operating temperatures would be encountered, the temperature and its influence on capacity must be considered. The use of battery insulation at high temperatures and currents could be a disadvantage though significant benefits are realized at lower temperatures as the following test sequences indicate.

The influence of retaining battery produced heat was studied with Battery BA-4386/PRC-25 surrounded by various thicknesses of thermal insulation. Rigid polyurethane, density 2.0 pounds per cubic foot, was used in these experiments. The 14.4 volt section of the BA-4386/PRC-25 was discharged at a relatively constant 5 watt drain to a 10 volt cutoff voltage. Results of this experimentation are shown in Table IV. At -25°F no capacity would be expected without insulation, but at least 7.7 hours of useful service were obtained when 3/8 inch or more insulation was employed. However, even with insulation the voltage delay time at -25°F can be quite substantial if the battery is cold soaked before discharge, but by starting with a warm battery the voltage delay is curtailed. At 20°F, battery capacity increased threefold when 1/8 inch thick insulation was used as compared to no insulation. The differ-

TABLE IV
SERVICE IN HOURS

Thickness of Insulation In Inches	Service At -25°F*	Delay In Minutes At -25°F	Service At 20°F	Service At 160°F
None	-	-	5.0	-
1/8	4.3	72	15	-
1/4	4.5	20	17, 15	27
3/8	7.7**	<1	17***	25.5
	9.0	60		
1/2	14.2**	<1	17****	
	11.4	15	19****	

*Delay time not included in service hours.

**Battery soaked 1/2 hour at minus 25°F before test began. All other batteries soaked 16 hours minimum.

***Discharged to 11.7 volts.

****Discharged to 11.0 volts.

ence in performance between the ½ hour and 16 hour soak periods may be due to variations in batteries. At 160°F, with ⅜ inch thick insulation, the surface temperature reached 183°F. This operating temperature would not have a severe negative influence on battery capacity since the service time is very near that presented in Table III for the 7.5 ohm discharge.

Hybrid/Insulation Combination

The advantages gained by hybridizing the Mg/MnO_2 Battery BA-4840/U with the Ni-Cd battery and also insulating the BA-4840/U against heat loss are shown in Table V.

TABLE V
MEAN SERVICE IN HOURS OF 14.4 VOLT SECTION OF BATTERY BA-4840/U

Table V. Mean Service in Hours of 14.4 Volt Section of Battery BA-4840/U

Loads in Ohms:		1.5/65*	2.5/100*
Battery Configuration	Discharge Temperature in °F	Service (Hours)	Service (Hours)
No Hybrid	70	15.9	27.8
	40	2.0 estimated	4.3
Hybrid	70	18.4	30.0
	40	14.5	24.2
Not Insulated	20	2.25	-
Insulated**	20	17.8	-

*Discharged on a 1/9 minute duty cycle, repeated continuously.
**3/8" rigid polyurethane, 2 pound/cubic foot density, encased in 0.10 inch steel walls.

For this experiment, Battery BA-4840/U was constructed with sixty-four cells, each one measuring 0.939 inches in diameter and 3.18 inches in height. The cells were connected in series-parallel to provide two nominal 14.4 volt sections, each section containing thirty-two cells, eight cells in series, four series stacks in parallel. The Ni-Cd cells used were of the sealed cylindrical type with a rated capacity of 250 mAh; two each were used in parallel to obtain 500 mAh. Nine of these 500 mAh Ni-Cd batteries in series were placed directly in parallel with each 14.4 volt section of the primary battery. Both sections of the battery were discharged simultaneously to an end voltage of 10 volts after the battery was at the test temperature for at least sixteen hours.

The results in Table V show that a hybrid configuration must be employed to obtain any significant performance at the indicated loads at 40°F. However, at 20°F the use of insulation increased the service hours almost eight times. No delayed action was exhibited by the hybrid design. The Ni-Cd battery portion of the system represents an increase in weight of 10.2% and an increase in volume of 11.5%, with both percentages based on the weight and volume of the Mg/MnO_2 battery. In a complete evaluation, the effect of insulation on overall equipment weight and volume should also be considered.

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